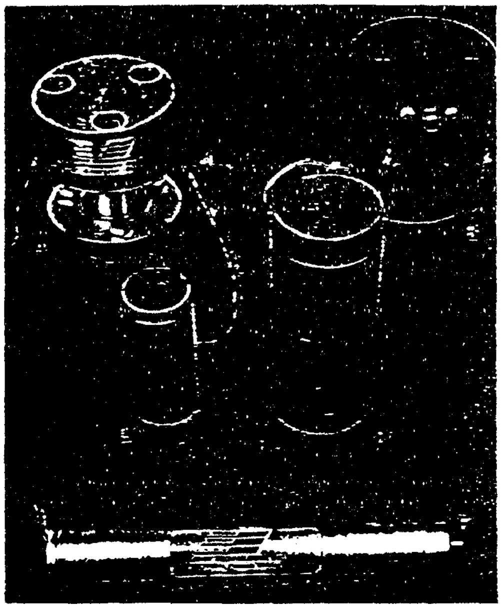
EDGE TECHNOLOGIES, INC.
ETREMA Products Division

MAGNETOSTRICTIVE ACTUATORS

Actuators powered by the magnetostrictive alloy ETREMA Terfenol-D® achieve accurate linear or oscillatory motion in response to a magnetic field generated by a low voltage electric current. In addition to the largest strain or change in dimensions of any commercially available material Terfenol-D driven actuators offer high force and microsecond response times. Applications include micropositioning, active antivibration, robotics, valve control, high force-high speed pumps, fast acting switches and relays and high energy sonic sources.



ETREMA TERFENOL-D® ACTUATORS
A. RA-101 or RA-102, B. RX-101, C. PM-50 or PN-50, D. PHM-75, E. LA-100

ADVANTAGES

HIGH DISPLACEMENT
HIGH ENERGY DENSITY/HIGH FORCE
LOW VOLTAGE OPERATION
MICROSECOND RESPONSE
BROAD FREQUENCY BANDWIDTH
EXCELLENT TEMPERATURE RANGE AND STABILITY
NO POLING, AGEING OR FATIGUE
BIDIRECTIONAL RESPONSE POSSIBLE

TERFENOL-D

Terfenol-D is an alloy of the metals terbium, dysprosium and iron with the formula $Tb_xDy_{1-x}Fe_y$. Exact stoichiometry can be customized for the properties demanded by each application. ETREMA Terfenol-D® is produced by patented processes licensed through Iowa State University and the United States Navy.

ETREMA actuators employ Terfenol-D rods of stoichiometry $Tb_{.3}Dy_{.7}Fe_{1.95}$. A typical performance curve is shown in figure 1. Strain or displacement due to magnetostriction is measured as change in length (ΔL) over length (L), or $\Delta L/L$, and is therefore dimensionless. The magnitude of the displacement is given as parts per million (ppm). For the curve shown in figure 1 application of a magnetic field of 500 Oersteds (Oe) will result in a strain of over 1000 ppm.

Figure 1 also shows that application of mechanical prestress is important to maximum performance. The width of the curve represents hysteresis. Terfenol-D will increase in length when a magnetic field is applied parallel to the drive axis. Reversing the field produces identical response.

Contact Edge Technologies, Inc. for more information on properties of Terfenol-D or for applications engineering to help development of your projects.

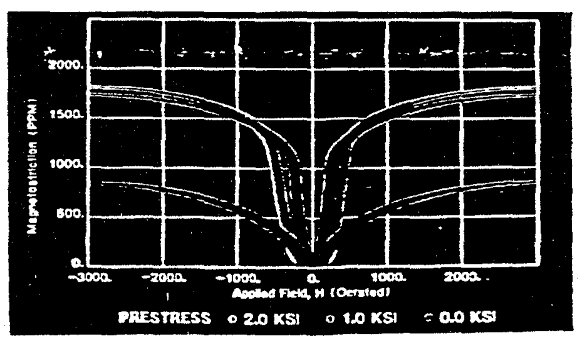


FIGURE 1. Typical performance of a Terfenol-D rod at three prestress levels.

PRESTRESS
- 2.0 KSI (13.8 MPA)
- 1.0 KSI (6.9 MPA)
- 0.0 KSI (0.0 MPA)

306 SOUTH 16TH STREET / AMES, IOWA 50010 / USA / 515-232-0820 / FAX 515-232-1177

ETREMA ACTUATOF

Three families of ETREMA actuators are available, both magnetically biased and unbiased. For a discussion of the correct unit in a given application see pages 3 and 4 of this brochure. Variations of stock actuators or complete custom designs are available by special order.

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THE LA-100

The LA-100 is a compact, non magnetically biased actuator supplied complete with internal mechanical prestress and ready to run. The mechanical bias is preset at the factory for maximum unloaded displacement. Data are supplied allowing adjustment of the spring loading for best results in a given application. For more information on LA-100 operating specifications request a copy of the instruction manual.

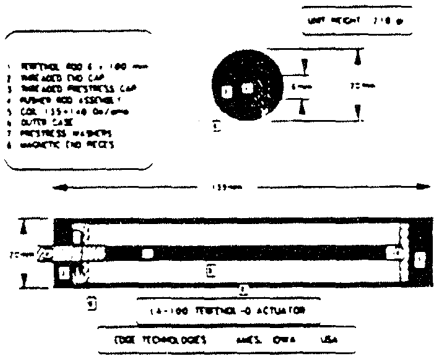

FIGURE 2. LA-100 Cross Section Drawing

THE RA SERIES

The RA series actuators are complete and ready to run with simple or complex laboratory equipment. The most common applications for RA actuators are introductory studies and demonstrations of magnetostrictive transduction.

Each RA actuator contains a complete magnetostrictive drive circuit from our P series. The RA-102 is driven by a PN-50 (nonmagnetic bias) and the RA-101 and RX-101 are driven by a PM-50 (magnetically biased). The RX-101 is encased in a black anodized aluminum sleeve for appearance and is supplied with a cable which allows immediate connection to a sonic source, such as a radio.

The RA actuator's prestress springs are factory set for optimal performance. Operating instructions with suggested experiments are included.

THE P SERIES

Actuators of the P series are available in a number of types for many applications. Mechanical loading must be provided by the driven device, otherwise the actuator is complete.

Both magnetically biased or unbiased actuators, as well as several stroke and load ranges, are available in stock P series actuators.

The flexibility of these actuators allows for easy production of similar custom units. For example, length can be changed for different maximum stroke. Contact the applications engineers at Edge Technologies, Inc. to discuss your requirements or for performance data.

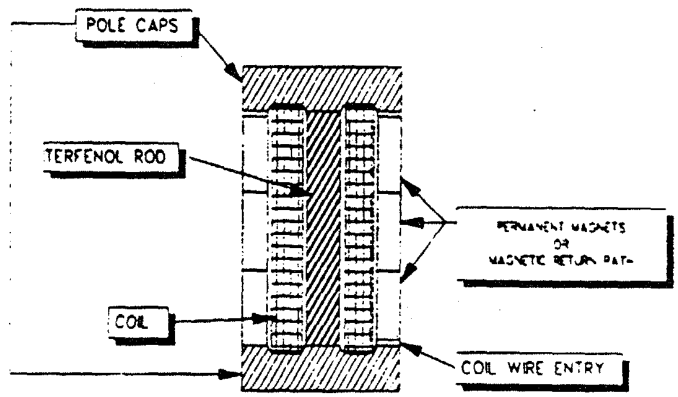

FIGURE 3. Typical P Series Actuator Cross Section Drawing

ETREMA TERFENOL-D® ACTUATORS SPECIFICATIONS

CATALOG NUMBER	LA-100	PN-50	PM-50	PHM-75	PHM-110	RA-102	RA-101	RX-101
Maximum Displacement (μm)	100	50	50	75	110	50	50	50
Peak (+/−) Amperage Input	3	2	2	3	4	2	2	2
Maximum Load (Kg)*	25	25	50	180	180	25	50	50
Magnetic Bias	no	no	yes	yes	yes	no	yes	yes
Spring Loaded (mechanical prestress)	yes	no	no	no	no	yes	yes	yes
Length (cm)	14.0	6.4	6.4	10.2	12.8	7.5	7.5	7.5
Diameter (cm)	2.0	2.54	2.54	3.8	3.8	6.0	6.0	6.0
Coil Resistance (Ohms)	2.3	6.4	6.4	3.5	5.0	6.5	6.5	6.5
Coil Field Rating (Oe/amp)	140	300	300	140	140	300	300	300
Terfenol Rod Length (cm)	10.0	5.0	5.0	7.5	11.4	5.0	5.0	5.0
Terfenol Rod Diameter (cm)	0.60	0.64	0.64	1.25	1.25	0.64	0.64	0.64
Price/each + Shipping	$1,000.00	$435.00	$450.00	$825.00	$1,125.00	$500.00	$500.00	$525.00

*Maximum load is the load the actuator will push at maximum rated displacement. At higher load the stroke will be less than the value given as maximum motion

ACTUATOR DESIGN NOTES

Elements of good actuator design are illustrated in figure 4, the cross section drawing for the RA series of actuators. The solenoid coil generates a magnetic field concentrated in the Terfenol-D. Response is proportional to the magnetic field and therefore proportional to the current in the coil.

To enhance selection or design of a magnetostrictive actuator for a given application consider the following discussion of some essential design elements.

DISPLACEMENT OR MOTION

Terfenol-D displacement or strain (λ) is expressed as $\Delta L/L$ where L is rod length and ΔL is change in rod length. Since $\Delta L/L$ is dimensionless the magnitude is given in parts per million (ppm).

Figure 1 shows performance expected of a typical Terfenol-D drive element. A strain of 1000 ppm can be achieved at an applied field of approximately 500 Oe. Thus, a typical 100mm long Terfenol-D rod will increase 100 μm in length when a 500 Oe field is applied.

In the specifications table for ETREMA actuators the maximum motion figure given is the **minimum** displacement which can be expected at rated amperage and load.

While displacement in a magnetostrictive actuator driven by Terfenol-D is highly reproducible, there is hysteresis. Accurate positioning may require a sensing device.

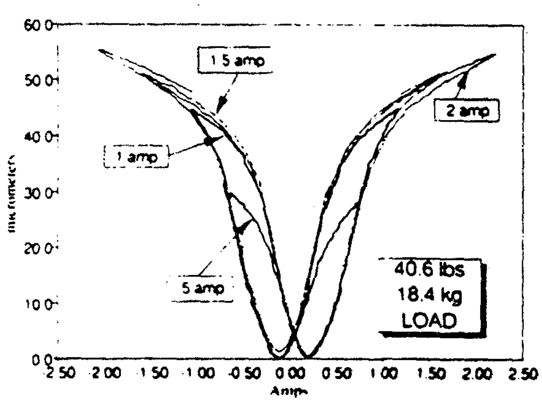

FIGURE 5. PN-50 Non magnetically biased Actuator Performance. Displacement at various current input levels.

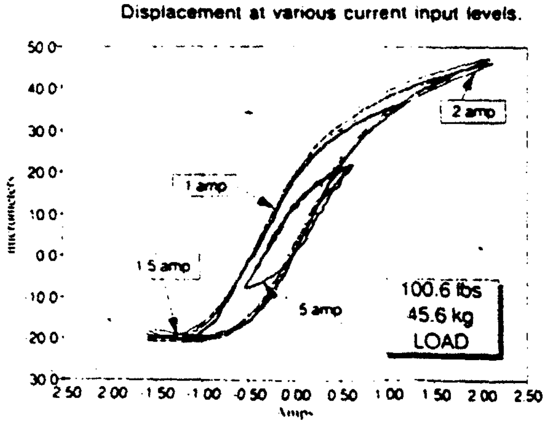

FIGURE 6. PM-50 Magnetically biased Actuator Performance. Displacement at various current input levels.

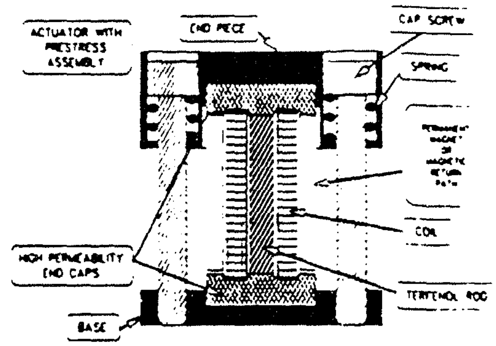

FIGURE 4. RA Actuator Cross Section Drawing

MAGNETIC CIRCUIT

Examination of any ETREMA actuator magnetic circuit illustrates how high magnetic flux density is achieved in the Terfenol-D with minimum current input. The pole or end pieces are high permeability iron. They help reduce fringing of the flux lines at the rod ends. The coil extends past the Terfenol-D ends, also improving flux density. In most actuators there is a provision for a magnetic return path, which is provided by high magnetic permeability material. When the Terfenol-D drive element is long in relation to diameter, as in the LA-100, a return path through air is sufficient.

In magnetically biased ETREMA actuators, the bias is provided by cylindrical permanent magnets, which also serve as the flux return path. Other methods of providing magnetic bias are also successful. For example, the magnets can be placed at the ends of the rods, or a "stack" of alternating magnets with Terfenol-D drive elements can be built

MAGNETIC BIAS

For linear operation under an ac field magnetic bias is required. Thus, most magnetostrictive actuators or transducers used for dynamic or oscillatory outputs employ magnetic bias. Bias may be supplied by a dc current, but use of permanent magnets is more common. If only positive displacement is required in a Terfenol-D actuator no magnetic bias may be needed. When an ac current is supplied to a non magnetically biased actuator, such as the PN-50, expansion of the Terfenol-D will take place on both halves of the input cycle; thus, actuator frequency will be twice the frequency of the input current. With a properly biased and preloaded actuator there will be expansion in one direction on the positive half of the cycle and contraction in the other direction on the other half of the cycle. The transducer can be made to operate in the linear portion of the strain vs field curve where the slope of the curve is greatest. Net displacement and efficiency will be maximized.

The effect of magnetic biasing is illustrated in figures 5 and 6 which show performance curves for the PN-50 and PM-50 actuators. These actuators are essentially identical, except that the PM-50 is magnetically biased. In the PM-50 cylindrical permanent magnets surround the coil and provide a bias field of about 200 Oersteds. The net displacement for a given input is higher for the PM-50 due to the contribution of the permanent magnet to the applied field. Note that if the magnetically biased actuator is "overdriven", the displacement curve will pass through the minimum position.

MECHANICAL BI… […RESTRESS]

As shown in figure 1, Terfenol-D achieves maximum performance when a proper prestress or mechanical load is applied. Application of appropriate mechanical preload also helps mate components and provides for low loss transfer of forces.

Stiffness of the prestress system should be kept low to avoid clamping the drive element. Dynamic transducers for applications such as sonar or geophysical mapping may employ a considerably greater prestress.

As the load is increased the slope of the strain vs field curve changes slightly. Higher displacements can be achieved in a loaded actuator, although more field is required to reach any given displacement value.

Varying the prestress in a magnetically biased actuator will allow some variation in response. Generally, the bias point is set to the center of the linear portion of the strain vs field curve to maximize bidirectional response. Adjustment of prestress can shift the rest position of an actuator to achieve this ideal bidirectional response.

FREQUENCY RANGE

Terfenol-D actuators can be designed for constant response over a broad frequency range. Response time of Terfenol-D material to application of a magnetic field is generally complete in under 10 microseconds. The mechanical load driven by a Terfenol-D actuator will usually determine the upper limit of the frequency range.

The frequency response of an ETREMA RX-101 actuator is shown in figure 7. In many applications the actuator will be operated in the linear region below the resonance frequency. Other applications can take advantage of the higher displacements available at and around resonance by operating close to the resonant frequency.

The resonant frequency of an actuator is determined, in general, by the stiffness of the Terfenol-D driver and the mass driven by the actuator. Longer, thinner drivers and larger masses will result in lower resonant frequencies.

Consult the *APPLICATIONS MANUAL FOR DESIGN OF ETREMA TERFENOL-D® MAGNETOSTRICTIVE TRANSDUCERS* for further details.

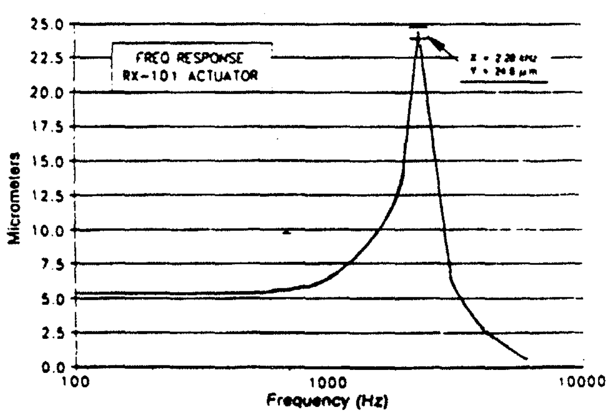

FIGURE 7. RX-100 Actuator frequency response.

COIL DESIGN

Coils for magnetic field generation in ETREMA actuators are of the "free standing" (no bobbin) type. They are designed to produce [illegible] intensity using low input power yielding high efficiency. Basic coil parameters are shown in the specifications table and detailed analyses of these coils are available on request. Custom wire sizes can be ordered at additional cost, but the physical dimensions of the coils are fixed by the actuator.

The Edge Technologies, Inc coil analysis computer program is available upon request. Some of the basic equations used to develop the best coils for each application follow.

ID = INNER DIAMETER
OD = OUTER DIAMETER
L = LENGTH
N = NUMBER OF TURNS IN COIL
α = OD/ID
β = L/ID

DIMENSIONS ARE IN CENTIMETERS

$$H = \frac{G(\alpha,\beta) \times 2\pi N I}{ID(\alpha-1)} \times \sqrt{\frac{\alpha^2-1}{2\pi\beta}}$$

$$G(\alpha,\beta) = .2\sqrt{\frac{2\pi\beta}{\alpha^2-1}} \cdot \ln\left(\frac{\alpha+\sqrt{\alpha^2+\beta^2}}{1+\sqrt{1+\beta^2}}\right)$$

$G(\alpha, \beta)$ is the GEOMETRY FACTOR. Used to simplify the field equation it is without units. It is also an indicator of the coil's power efficiency. The maximum theoretical value is 0.179. Setting I = 1amp yields an estimate of the field strength at the center of the coil in Oersteds. This is the Oe/amp rating shown in the specifications table.

FORCE GENERATION

The high energy density of Terfenol-D allows actuators driven by this material to achieve higher forces than other compact actuators. The clamped force generated by a Terfenol-D rod is given by $F = EA\,\Delta L/L$ where E is Youngs Modulus (3.5×10^{10} N/m²) and A is cross section area in m². Stock actuators with various rod diameters and load ranges are available.

Figure 8 shows displacement vs load for a PHM-75 actuator at various input levels. Displacement is bidirectional since the actuator is magnetically biased. A maximum load figure is given in the specifications table for each ETREMA actuator. Larger loads can be driven, but with some loss of displacement.

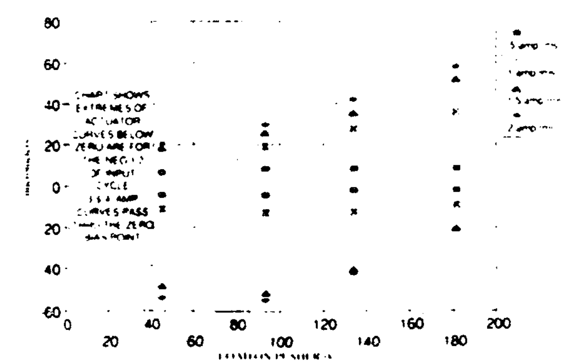

FIGURE 8. PHM-75 Actuator Stroke vs Load at Various Input Levels

ORDERING INFORMATION

ETREMA actuators in this brochure are generally available from stock. To order contact

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For additional information on properties and applications of Terfenol-D or actuators and other devices powered by these magnetostrictive materials, contact us at the address shown.